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STUDY OF UPPER ATMOSPHERE WIND MOTIONS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the efforts at UT Dallas to evaluate the crosswind measuring capability of the AFGL accelerometers (MESA's) mounted on the Atmosphere Explorer satellites. The software available for this purpose from AFGL had some limitations that prevented its use for our purposes, and much of our contract time was devoted to producing a suitable software package. Using this, we find that the wind data from all three spacecraft are probably useful, though the AE-D data are somewhat noisier than that from AE-C and AE-E.

Both AE-D and AE-E have another device (NATE) on board that measures the

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20. same wind component as MESA. Our limited comparisons of these measurements show that they are in reasonable agreement. We suggest that a substantial amount of MESA wind data from these two satellites be processed in order to make a careful comparison with the NATE.

On AE-C NATE does not measure the horizontal wind component, and we suggest that the MESA wind data for this satellite be processed in its entirety (for the elliptic orbit phase) and be placed in the UA file. Fortunately, the AE-C MESA data are the cleanest of all.

TABLE OF CONTENTS

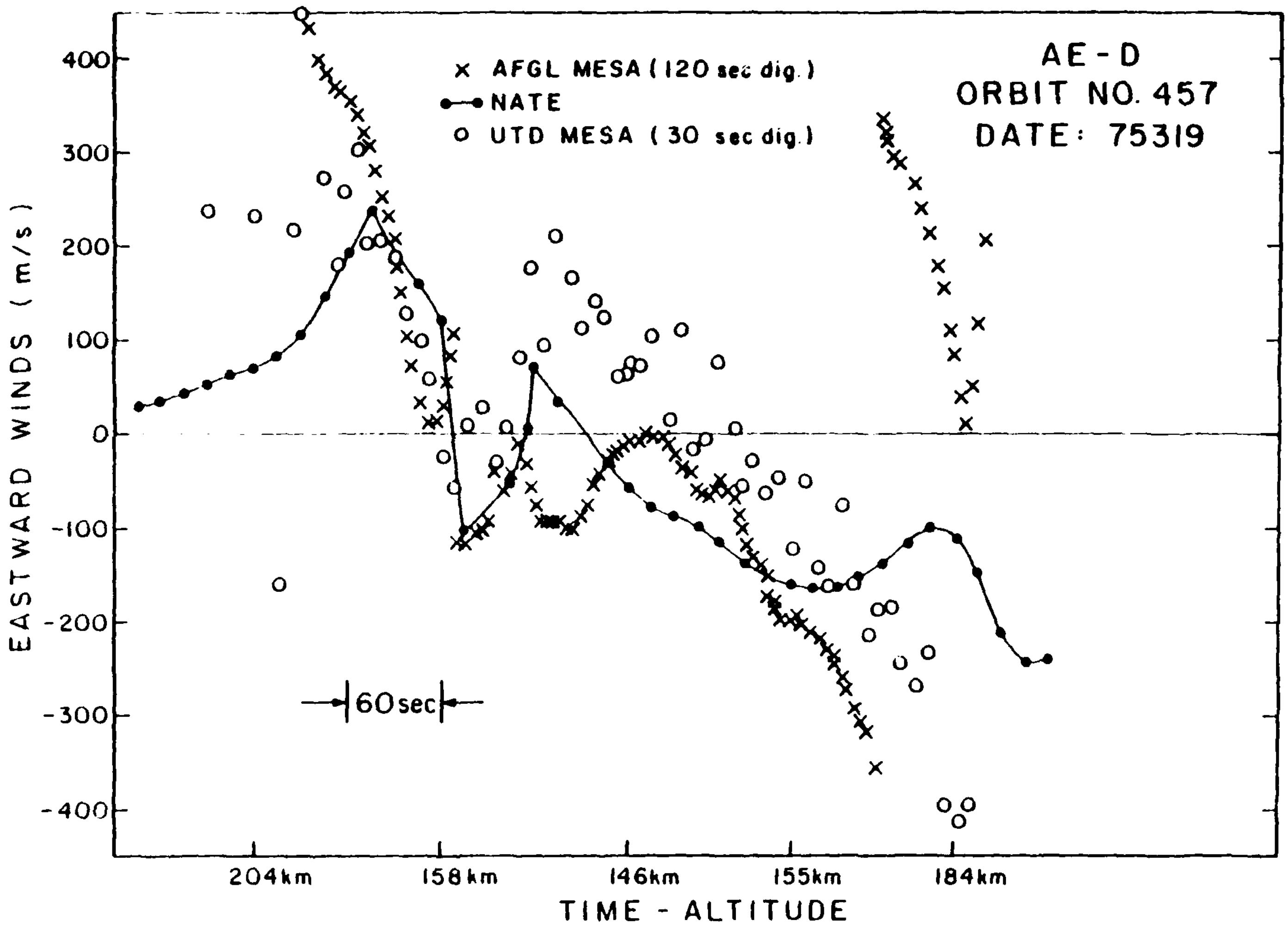
INTRODUCTION

The AFGL Miniature Electrostatic Accelerometer (MESA) on the Atmosphere Explorer (AE) satellites was designed to provide neutral atmospheric density measurements by determining satellite deceleration caused by aerodynamic drag. Each spacecraft contained three single-axis sensors. The first is aligned with the Z (spin) axis, while the other two sensors (designated XY and YX) are located in the X-Y plane at a 45° angle on either side of the +X axis. The sensors have the capability of being commanded into any of three sensitivity ranges, with the least sensitive being only used for satellite thrust monitoring. The focus of our effort has been the utilization of the data from these three sensors to determine the velocity of the component of neutral atmospheric winds lying along the spacecraft Z axis during those periods when spacecraft altitude was low enough (<180 km) for accurate measurements.

The first section of the report discusses the software package that was put together at UTD to calculate the winds from the MESA telemetry data. This is followed by a discussion of the application of this software to actual MESA data. Results are then plotted and compared with NATE data, and the outputs of different filters are examined. Finally, some recommendations for MESA data analysis are presented.

SOFTWARE

The first step was the examination of the results of the AFGL MESA Data Reduction System (DRS), which included a preliminary wind estimate. It was initially apparent that the contribution to the winds of atmospheric corotation (~500 m/sec) was not included. In addition, the computed values showed sudden large discontinuities (see Figure 1). The cause of these effects required futher study. Also it was desirable to investigate the effectiveness of the digital filter used to remove noise from the data. For these reasons it was decided to develop an independent program to analyze the MESA data and compute the neutral winds. The software package developed is described in the following paragraphs.



AE - D
ORBIT NO. 457
DATE: 75319
× AFGL MESA (120 sec dig.)
NATE
○ UTD MESA (30 sec dig.)
EASTWARD WINDS (m/s)
400
300
200
100
0
-100
-200
-300
-400
60 sec
204km
158km
146km
155km
184km
TIME - ALTITUDE

FIGURE 1

To simplify calculations and to achieve maximum accuracy it was decided to use only data from despun passes. In addition, the program does not require any input from the MESA data reduction file system developed at the AFGL, using only the TM data base and orbital and attitude information from the AE Central Computer Facility at Goddard Space Flight Center. The program converts the TM data to MESA raw data, applies a temperature correction to the data, utilizes a filter to eliminate noise due to the satellite's momentum wheel assembly, and finally calculates the velocity of the neutral wind along the Z-axis of the satellite, producing a line printer plot of Z axis wind versus G.M.T. The Z axis wind was calculated from the formula:

$$W_Z = |\bar{V}_s'| \frac{(a_Z + |\bar{a}_+| \cos\alpha)}{|\bar{a}_+|} \qquad (1)^*$$

where W_Z is the Z axis wind, a_Z is the Z axis acceleration, $\bar{V}_s'$ is the satellite velocity in the earth's rotating frame of reference, $\bar{a}_+$ is the total satellite acceleration, and α is the angle between the Z axis and the satellite velocity vector. Total satellite acceleration may be determined either by using the output from all three sensors or by utilizing only the XY and/or YX sensor and correcting for the angle between the sensor and the spacecraft velocity vector.

Control and Input Data

Basic program control is simple. The major required parameters are satellite identification, start and stop dates and times, sensor(s) to be used to compute total drag, reference frame for wind calculation (corotating or non-corotating), and number of data points used in the filter. The program then proceeds to extract from the AE data base all data necessary, including raw TM data, sensor temperature, range indication, overflow flags, and position, attitude and velocity information.

Temperature Correction and Filtering

Raw TM data is first temperature corrected and then fed into a buffer from where it is then passed through a filter to remove momentum wheel and nutation noise. One of the filters used is the "15-10" filter developed at AFGL for use on the MESA system.

*See Appendix.

Wind Determination

Data from above 280 km altitude is used to establish a zero acceleration baseline for sensor response. Then using the XY sensor, the YX sensor, or all three sensors, the total drag induced deceleration of the vehicle is determined. Using the known attitude and velocity of the satellite, Equation 1 is then applied to yield the Z axis wind.

Overranging

When one of the sensors is in its most sensitive range it can happen that the acceleration along that axis may exceed the maximum (2×10^{-5} g) for that range. When this occurs an overrange flag is signaled in the telemetry for that sensor. When the XY or YX sensor is being used to determine total drag, an overrange condition causes that data point to be dropped. In intervals where the Z axis sensor overranges no useful wind information can be obtained from the present software, but it is likely that data could be recovered in these regions with a little more effort. This ususally occurs only below 140 km altitude.

Output

The program output consists of four data files. The first consists of processed analog data. The second contains processed digital data (this is the main output file). The third contains a line printer plot of the Z axis wind. The last is a file indicating data dropped due to errors or overranging.

PROGRAM APPLICATIONS

Since there is no existing wind data base from NATE for AE-C this satellite performance is most critical from an overall AE-science consideration. In the course of data reduction several constraints upon the usage of the Winds program in regard to AE-C data become apparent.

One problem exists regarding the calibration of the XY and YX sensors. If during the course of a low altitude pass one uses the accelerat on computed from one of these sensors and the orientation angle of that sensor relative to the direction of satellite velocity one can obtain a value for the total drag induced acceleration of the vehicle. If this is done for each of the two spin plane sensors one consistently finds that they are in disagreement, with the XY sensor giving values approximately 10 to 20% larger than those from the YX sensor. This seems to indicate the need for an in-flight calibration, and this can perhaps be achieved by utilizing the density measurements from the onboard neutral mass spectrometers.

A second concern is that of the sensitivity ranges of the sensors. The standard mode of operation appears to have been to leave the YX and Z sensors in their most sensitive range (range 3) while leaving the XY sensor in range 2. While this practice yields the maximum amount of information in regard to total atmospheric density, it requires that the XY and YX sensors be intercalibrated to produce a smooth wind profile, since each is used for part of each pass. The YX sensor saturates and overranges below 150 km altitude, forcing us to use only the XY sensor for total drag determination below this altitude.

In the case of the AE-D and AE-E satellites it was found that the XY and YX were also left on ranges 2 and 3 respectively. The Z sensor, however, was not set on the most sensitive range but instead on range 2. This degrades the accuracy of wind determination using these two spacecraft, but not by a large factor, because the signal to noise level is fairly low so that the extra gain (x 20) going from range 2 to range 3 does not help too much (i.e. the signal is large enough to be seen on range 2.)

WIND RESULTS

Because of the short time available to examine MESA wind data after the new software was checked out the conclusions reached here are somewhat tentative. A total of approximately 40 orbits from all three satellites provide the basis for this report.

The AE-D data plotted in Figure 1 show a comparison of the east-west wind component as determined by the program developed here, by the AFGL program, and by the NATE instrument. Except for the regions where the AFGL result has an apparent sign difficulty, the three sets of data are in general agreement. The smoother appearance of the AFGL output compared to the UTD points arises because of much heavier filtering (a two-minute filter compared to a 30-second filter). Some of the AE-D MESA data is quieter than that shown here, and some is noisier, but there is much useful data even though the Z axis accelerometer was on the middle sensitivity range.

Perigee was near 82° north *latitude on orbit* D-457 so that the wind pattern may be reasonable in spite of its structured appearance.

A more detailed comparison of the various filter outputs is shown in Figure 2, which also uses data for orbit D-457 (note the change in sign of the wind coordinate). Data points are plotted every 10 seconds. All the curves have pretty much the same general characteristics except for the slightly higher noise level with the narrower filters. The simple running filter seems to be as effective as the much more sophisticated digital filter.

There is no wind data with which to compare on AE-C, but the results obtained from the sensors using current software are consistent with those expected on a theoretical basis. Figure 3 presents two typical equatorial passes recorded nineteen days apart on the AE-C satellite. Note that in both cases there exist data gaps near perigee due to the saturation of the Z sensor (not all points are saturated, only those with large noise spikes). In addition, the effects of atmospheric corotation have been removed, corotation introducing an easterly bias of approximately 450 m/sec near the equator. The perigees of orbits 2830 and 3086 occur at a Solar Local Time (SLT) of about 16:40 and 12:00 respectively. Models of the wind velocity determined from atmospheric pressure gradients predict zonal wind velocities of about 100-150 m/sec in these regions, with the wind at 12:00 SLT being westward and the wind at 16:00 SLT being eastward. Indeed, the data do reveal a westward to eastward shift in the wind velocity near perigee with the magnitude of the change being about 110 m/sec. The noise level of the rest of the AE-C data examined is of comparable magnitude. In general, this noise level is probably smaller than the absolute uncertainty in the winds arising from errors in the spacecraft attitude. The results certainly appear to be of useful quality for AE-science purposes.

A comparison of the NATE wind data from AE-E with that from MESA is shown in Figure 4 for orbit 385. There is a general consistency between the two results though there is an offset of 40 to 50 m/s near perigee. This discrepancy is not a great deal greater than the uncertainty in the mounting position of the devices within the spacecraft. From a comparison of a large data base of NATE winds with the ion drift meter results from AE-E, we also find an offset between the devices of the order of 50 m/s. This offset is slowly varying in time (weeks to months) and is not yet understood.

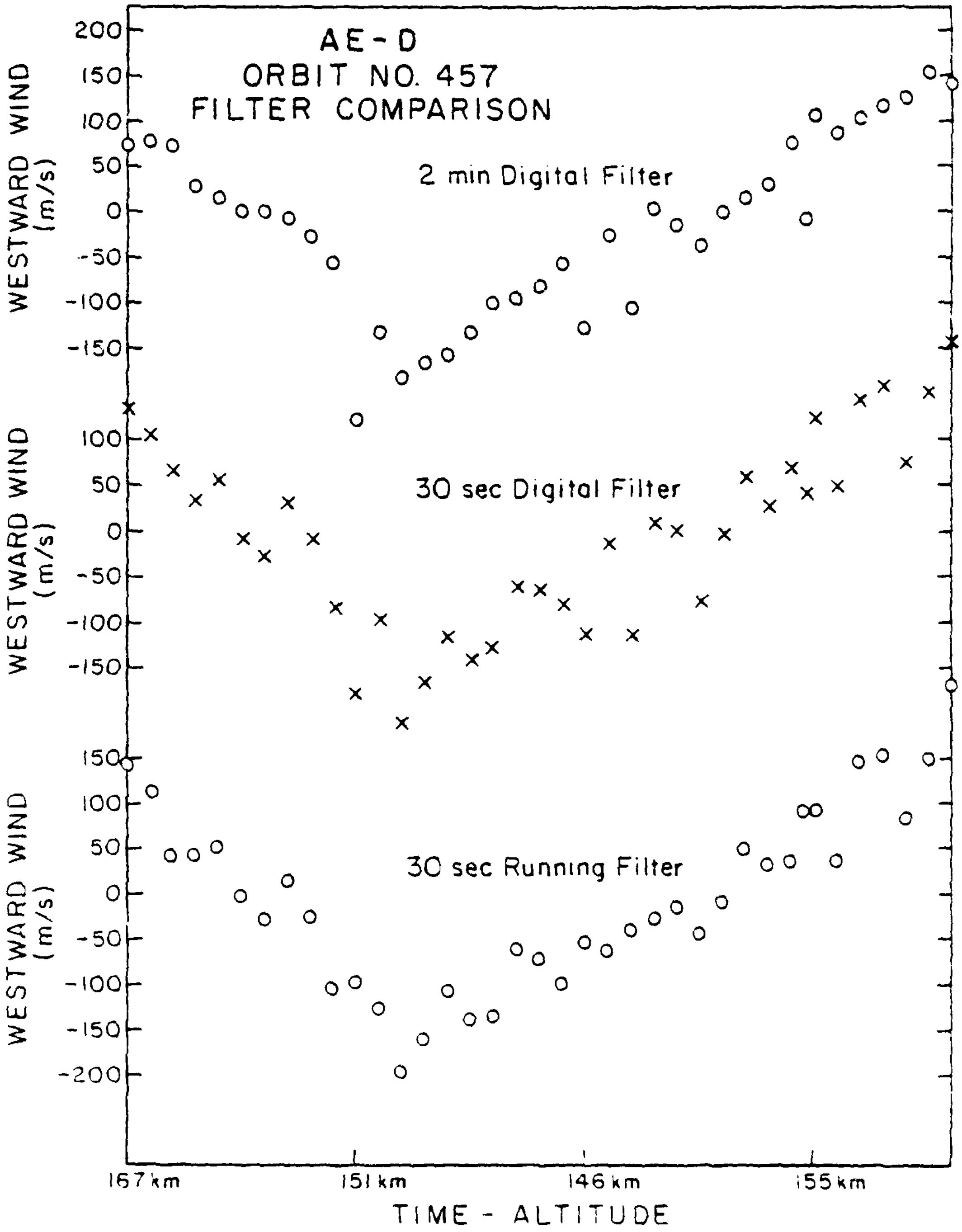

AE-D
ORBIT NO. 457
FILTER COMPARISON
2 min Digital Filter
30 sec Digital Filter
30 sec Running Filter
WESTWARD WIND (m/s)
WESTWARD WIND (m/s)
WESTWARD WIND (m/s)
200
150
100
50
0
-50
-100
-150
-200
167 km
151 km
146 km
155 km
TIME - ALTITUDE

FIGURE 2

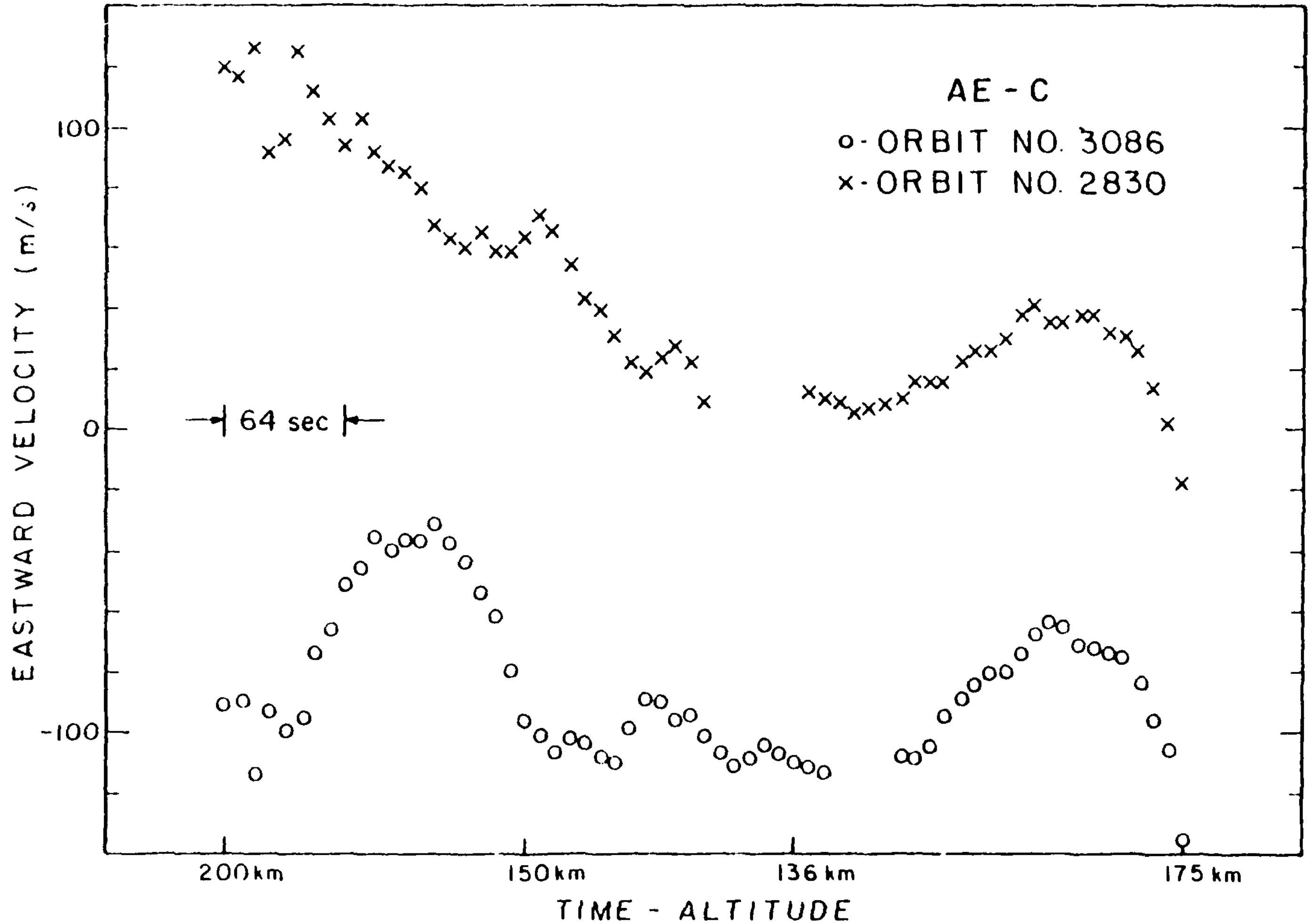

AE - C
o - ORBIT NO. 3086
x - ORBIT NO. 2830
64 sec
EASTWARD VELOCITY (m/s)
100
0
-100
200km
150km
136 km
175 km
TIME - ALTITUDE

FIGURE [illegible]

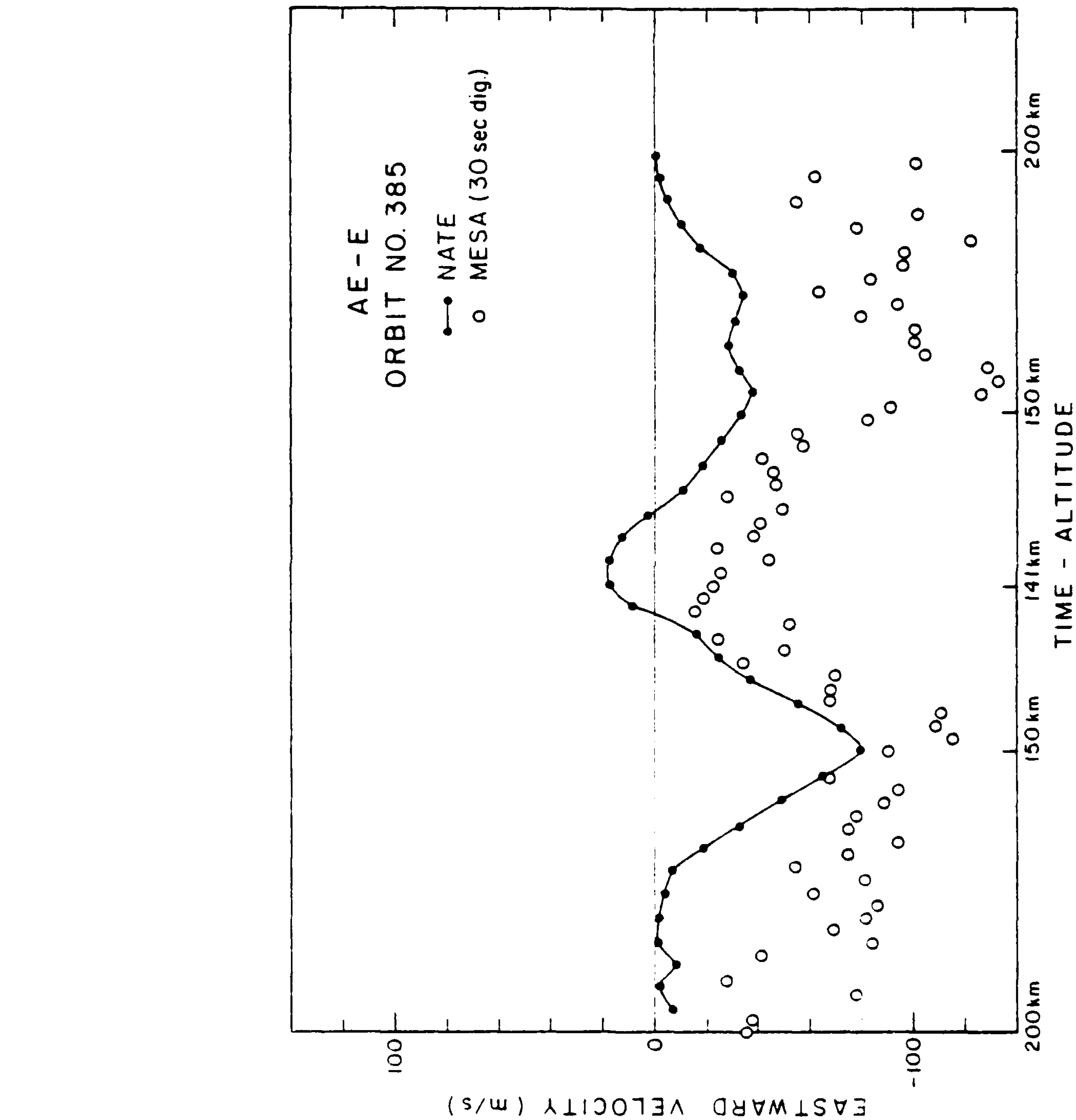

AE - E
ORBIT NO. 385
NATE
MESA (30 sec dig.)
EASTWARD VELOCITY (m/s)
100
0
-100
200 km
150 km
141 km
150 km
200 km
TIME - ALTITUDE

FIGURE 4

SUMMARY AND RECOMMENDATIONS

In summary, the technique of using accelerometers on a low altitude satellite to determine the transverse neutral wind appears to provide valid measurements. Though a relatively high noise level is present on the AE satellites, the current MESA sensors are adequate to provide a reasonable wind determination, particularly when the Z axis sensor is in its most sensitive range, as in the case of AE-C. AE-D and AE-E orbits, which have a slightly higher noise level, are nevertheless valuable in that NATE wind data provides a comparison between different techniques and can be used to build confidence in the AE-C orbits. This data should be completely analyzed and the results placed in the Unified Abstract (UA) files for reference by all interested researchers. A word assignment for MESA wind already exists in the UA files.

We did not expend any effort to examine the usefulness of the spinning data, but it is probably worth some effort to establish whether this data is of any value also.

It may be that the MESA data from both AE-D and AE-E should also be completely analyzed and placed in the UA files. Certainly a relatively thorough comparison with the NATE data should be made, if for no other reason than to determine the proper confidence to be placed in the technique for the AE-C wind users. This is probably a matter that might be discussed with the AE-science team.

At UTD we have developed a data analysis program monitor in connection with the processing of the RPA and MIMS data from AE. If this scheme were implemented for MESA, the further effort involved to complete the data analysis, place the data in the UA file, and provide a film plot of each orbit processed would be minimal. The program would have to run in the MESA Account. If this plan is to be given consideration, it should be implemented soon, because of the impending loss of the .9 computer for AE data processing.

PERSONNEL

A list of scientists, engineers, technicians, and programmers who contributed to the work is given below:

W.B. Hanson, Principal Investigator

W.R. Coley, Co-Investigator

R.A. Heelis, Co-Investigator

R.A. Power, Programmer

J.K. Lowell, Programmer

C.R. Lippincott, Project Manager

There were no previous or related contracts or previously produced publications or articles resulting from total or partial sponsorship of this contract.

APPENDIX

Neutral Wind Measurement

We desire to use the measured drag force $\overline{F}$ on a satellite to determine the neutral gas winds ($\overline{W}$). We can write (in the satellite frame):

$$\overline{V}_n = -\overline{V}_s + \overline{\omega} \times \overline{R} + \overline{W} \tag{1}$$

where $\overline{V}_n$ = total neutral gas velocity in the satellite frame

$\overline{V}_s$ = satellite velocity

$\overline{\omega}$ = earth's angular velocity

$\overline{R}$ = satellite position vector

$\overline{W}$ = neutral wind in earth's rotating frame of reference.

The drag force on the satellite is:

$$\overline{F} = 1/2 \ \rho A C_D \ |\overline{V}_n| \overline{V}_n \tag{2}$$

where ρ = atmospheric density

C_D = drag coefficient in direction of $\overline{V}_n$

A = presentation area normal to $\overline{V}_n$ of satellite.

Assume the satellite is oriented with its $\hat{X}$ axis approximately in the ram direction and with its $\hat{Z}$ axis horizontal. Then the acceleration components are:

$$a_z = \overline{F} \cdot \hat{Z}/M \tag{3}$$

$$a_x = \overline{F} \cdot \hat{X}/M \tag{4}$$

where M = satellite mass.

We also note that $\bar{V}_n$ is parallel to $\bar{a}_+$ where $\bar{a}_+ = a_x \hat{X} + a_y \hat{Y} + a_z \hat{Z}$.

Making the substitution $\bar{V}_s' = \bar{V}_s - \bar{\omega} \times \bar{R}$ we can rearrange (1):

$$\bar{W} = \bar{V}_n + \bar{V}_s' \tag{5}$$

or looking at just the Z component

$$W_z = V_{nz} + V_s'{}_z \tag{6}$$

Using eq. (3) and (4) we can show

$$\frac{a_z}{a_x} = \frac{V_{nz}}{V_{nx}} \tag{7}$$

Using the definition of V_{nx}:

$$V_{nx} = V_n \cdot \hat{X}$$

$$= |\bar{V}_n| \frac{\bar{a}_+}{|\bar{a}_+|} \cdot \hat{X}$$

$$= |V_n| \frac{a_x}{|\bar{a}_+|} \tag{8}$$

Using eq. (2) to eliminate $|\bar{V}_n|$ in eq. (8) we can then substitute this expression for V_{nx} into eq. (7) and get:

$$V_{nz} = a_z \left(\frac{2M}{\rho A\ C_D\ |\bar{a}_+|}\right)^{1/2} \tag{9}$$

Thus the expression for the Z component of the neutral wind becomes:

$$W_z = a_z \left(\frac{2M}{\rho A\ C_D\ |\bar{a}_+|}\right)^{1/2} + V_s'{}_z \tag{10}$$

$V_s'_z$ depends only on satellite position, velocity and the earth's rotation. These parameters can be obtained from the orbital-attitude data of the A.E. computer facility. However, an independent value of ρ is also required.

Alternatively, using equations (6), (7), and (8) we can eliminate the dependence of W_z on the magnitude of ρ or C_D, and obtain:

$$W_z = |\bar{V}_n| \frac{a_z}{|\bar{a}_+|} + V_{sz}' \qquad (11)$$

Thus the fact that C_D and A depend on the angle of attack is cancelled out if Equation (11) is used. But even if Equation (10) is used, it is not likely that C_D will change very greatly over the small angles of attack normally encountered (<10°).

Making the approximation $|\bar{V}_n| = |\bar{V}_s'|$ Equation (11) becomes:

$$W_z \doteq |\bar{V}_s'| \frac{a_z}{|\bar{a}_+|} + \bar{V}_s' \cdot \hat{Z} \qquad (12)$$

or

$$W_z \doteq |\bar{V}_s'| \frac{(a_z + |\bar{a}_+| \cos\alpha)}{|\bar{a}_+|} \equiv W_z' \qquad (13)$$

where α = angle between $\bar{V}_s'$ and $\hat{Z}$.

Equation (13) is the same as Equation (1) in the text, and is used in the UTD winds program to determine W_z. Without an accurate independent measurement of ρ no determination can be made of the other components of $\bar{W}$.

Estimate of Error. The validity of the approximation $|\bar{V}_n| = |\bar{V}_s'|$ may be examined under typical conditions.

Using (11) and (13)

$$W_z = W_z' + (|\bar{V}_n| - |\bar{V}_s'|) \frac{a_z}{|a_+|} \qquad (14)$$

we know $(|\bar{V}_n| - |\bar{V}_s'|) \leq |\bar{W}|$

and typically $a_z/|\bar{a}_+| \leq 0.08$

So for a 200 m/s wind the error term in (14) is $\leq$ 16 m/s.

A secondary source of error is introduced in that $|\bar{a}_+|$ is typically determined by using only one sensor and making the assumption that the neutral wind velocity is anti-parallel to the satellite velocity, thus we can write:

$$|\bar{a}_+| = a_x \,/\, (\hat{X} \cdot \frac{\bar{V}_n}{|V_n|})$$

$$\doteq a_x \,/\, (\hat{X} \cdot \frac{-\bar{V}_s'}{|V_s'|}) \qquad (15)$$

For $|\bar{W}|$ = 200 m/sec this leads to a maximum 2.7% error in $|\bar{a}_+|$. Using (12) this implies an error $\leq$ 16 m/s. Thus, these two sources of error are about equal in magnitude.

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